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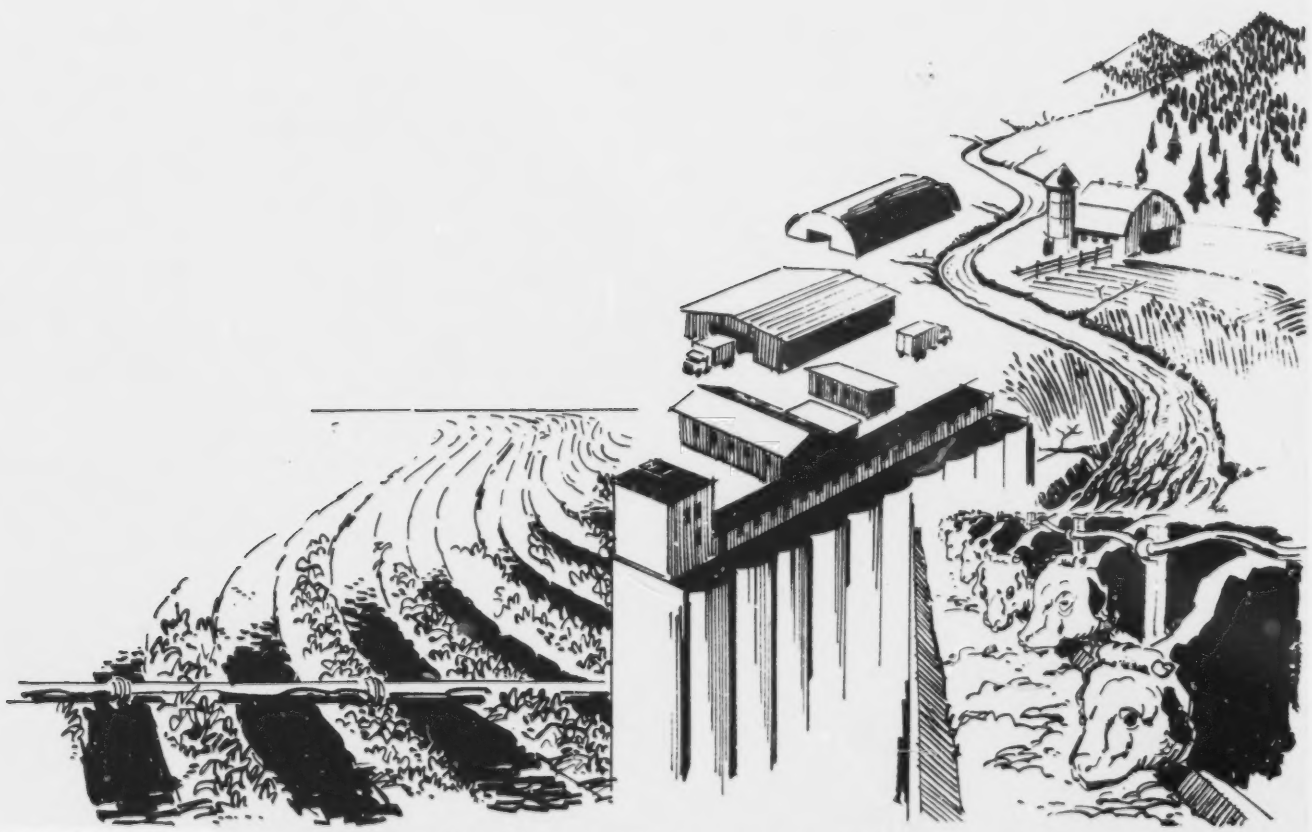
National Irrigation Return Flow Research and Development Program



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The status of the National Irrigation Return Flow Research and Development Program is presented. Current research projects and future program development are discussed. The report represents the position of the Environmental Protection Agency (EPA) with regard to the development of effective controls on the quality of irrigation return flows. Program goals and milestones are outlined. A number of potential control measures are discussed. Improvements in the water delivery system, on-the-farm water management, and the water removal system are considered with respect to improving the quality of irrigation return flows and decreasing the degradation of receiving waters. Research and investigations are needed to evaluate the effectiveness of potential control measures. Demonstrations and educational activities will be required to overcome institutional, political, and legal constraints to water management reform. ~~(Law-EPA)~~

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NATIONAL IRRIGATION RETURN FLOW

RESEARCH AND DEVELOPMENT PROGRAM

by

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for the

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The status of the National Irrigation Return Flow Research and Development Program is presented. Current research projects and future program development are discussed. The report represents the position of the Environmental Protection Agency (EPA) with regard to the development of effective controls on the quality of irrigation return flows. Program goals and milestones are outlined. A number of potential control measures are discussed. Improvements in the water delivery system, on-the-farm water management, and the water removal system are considered with respect to improving the quality of irrigation return flows and decreasing the degradation of receiving waters. Research and investigations are needed to evaluate the effectiveness of potential control measures. Demonstrations and educational activities will be required to overcome institutional, political, and legal constraints to water management reform.

Key Words: Irrigation return flow, water quality, pollution control, pollution abatement, agricultural wastewater.

CONTENTS

Section		Page
I	Summary and Conclusions	1
II	Introduction	3
III	Research and Development Program	9
IV	Future Program Development	13
V	Potential Control Measures	17
VI	References	23

FIGURES

		Page
1.	Model of the Irrigation Return Flow System	4
2.	National Irrigation Return Flow Research, Development, and Demonstration Program - Goals and Milestones	16

TABLES

No.		Page
1	Research Need Statements PPBS 13030 Subprogram Element, Irrigation Return Flows	7

SECTION I

SUMMARY AND CONCLUSIONS

The status of the National Irrigation Return Flow Research and Development Program is presented. Early program development and current extramural research projects supported by grant funds are discussed. Plans for future program development represent the position of the Environmental Protection Agency (EPA) with regard to the development of effective controls on the quality of irrigation return flows. Program goals and milestones required for their accomplishments are outlined. Basically, the practice of irrigation has detrimental effects on environmental water quality. Practical means for alleviating and/or controlling water quality degradation of surface and ground water resources from irrigated agriculture are urgently needed. Where control measures are not already apparent, research will be required to develop criteria for effective solutions.

There are a number of control measures that can improve the quality of irrigation return flows. The water delivery system can be improved by lining canals and laterals, using closed conduits for water transportation, providing adequate control structures, and requiring flow measuring devices. Improved management practices on the farm would include use of new irrigation application methods, scientific irrigation scheduling to insure proper timing and amount, more closely controlled leaching, judicious use of slow-release or other controlled fertilizers, tailwater recovery and reuse, and specialized cultural practices. In the water removal system, both tile and open drains may be employed to collect waste waters, which can then be diverted away from the river system or subjected to treatment prior to discharge or reuse. Economic considerations are important in selecting these methods.

Research and investigations will play leading roles in evaluating the effectiveness of potential control measures. Demonstrations and education will be required to disseminate the knowledge and experience needed to overcome institutional, political, and legal constraints to water management reform.

SECTION II

INTRODUCTION

It has long been recognized that the quality of water draining from irrigated areas was seriously degraded from that of the irrigation water applied. Agriculturists have viewed this as a natural consequence of the processes involved, and little attention has been given to the possibility that progress could be made toward controlling or alleviating the contributions of mineral salts and nutrients to our nation's water resources. Recent Federal legislation and a greatly increased national concern have caused a reversal of this attitude, and EPA has been charged "to establish a national policy for the prevention, control, and abatement of water pollution" (1). The water quality problems associated with irrigation return flows are of special concern because irrigated agriculture is the largest consumer of public water resources. It also is of major importance to the economy of a large segment of the nation and the supplier of a significant part of the food and fiber produced annually.

Irrigation Return Flow System

The complexities of the irrigation return flow system are portrayed schematically in Figure 1. The model shows the primary sources of return flow to be canal seepage, bypass water, deep percolation, and tailwater or surface return flow. Each of these can be subjected to some degree of manipulation or control through improved management techniques. Bypass water is chiefly a water resource or conservation problem, since few pollutants are added by simply flowing through the canal system. It is required for the purpose of maintaining head and adequate flow through the canal system and is usually returned directly to the river. Canal seepage, on the other hand, contributes to high water tables, aggravates subsurface salinity, encourages phreatophyte growth, and generally increases saline subsurface drainage from irrigated areas. Canal seepage can be a significant fraction of the total diversion in many project areas (2). Once water is applied to irrigated cropland, tailwater and deep percolation are the major contributors to irrigation return flow. These sources are the conveyors of nutrients and salts to the stream drainage system.

The areas of research pertinent to the control of water quality degradation in irrigation return flows are concerned with prediction techniques, treatment methods, and/or water management practices. Research needs to date indicate a strong emphasis on the later as the most promising approach to the control of nutrients and salinity at the source.

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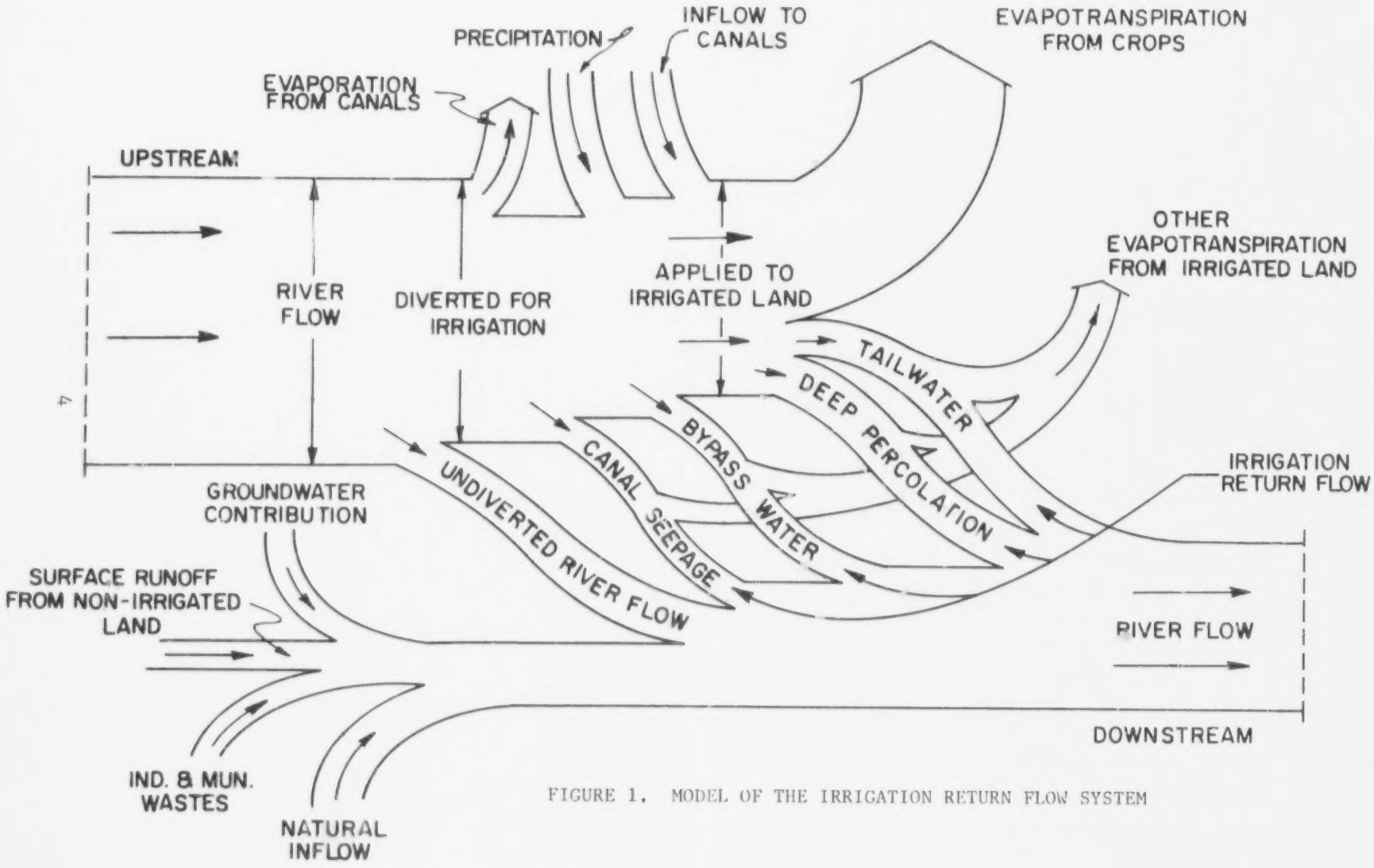

FIGURE 1. MODEL OF THE IRRIGATION RETURN FLOW SYSTEM

Statement of Problem

The major pollution factor associated with irrigation is the increased concentration of mineral salts in the drainage water. Irrigation is by far the major user of water in our western states and is responsible for much of the salt load carried by many of our western river systems. The control of pollutants contributed by irrigation is not an easy problem to attack, nor is it likely that irrigation will be abandoned because it degrades the quality of our water resources. Historically, irrigation practices have developed more as an art than a science. The principal scientific endeavors to date have been aimed at increasing crop yields and improving the design of distribution systems with little or no regard for the resulting water quality degradation. Salt balance studies have been performed on district-wide or basin areas to determine the ratio of total salt leaving to that entering the area, but these have not led to recommendations for any measure of control over salt-loading to a river system. Their value has been questioned on the basis that sources of the salt leaving an area have not been positively identified. They usually fail to show that all irrigated areas are under a favorable salt balance or that some areas are not accumulating salt while others are contributing salt from extraneous sources (2). Application practices (and malpractices) have been based more on the convenience of the irrigator and protection of his water rights than on scientifically tested management techniques. Research should now be aimed at reversing this trend and demonstrating that proper water and fertilizer management practices can indeed be an effective and feasible means of improving the quality of irrigation return flows. Hopefully, the direct result of such efforts will be a decrease in the pollutants contributed by irrigation to our surface and groundwater resources.

Program Goals

The major goal of the National Irrigation Return Flow Research and Development program is to find practical and economically acceptable means to control the salinity and nutrient contributions of irrigated agriculture to our surface and groundwater resources. This can be broken down and stated in several more specific objectives as follows:

a. Gain knowledge relative to prediction techniques, management practices, and treatment measures that may be applied to water quality problems of irrigation return flow.

b. Evaluate the effect of present irrigation practices on salt loads entering river systems, particularly through groundwater seepage.

c. Demonstrate that improved farm water management offers feasible means of minimizing salt and nutrient degradation of return flow without sacrificing crop yields.

d. Develop recommendations and guidelines on irrigation practices, methods, and systems which would have the greatest effect of reducing nutrients and salts in return flow while maintaining an acceptable salt balance in the root zone.

Development of the program goals has been through research need statements submitted and coded into the Program Planning and Budgeting System (PPBS). The originator of each need statement was asked to describe the specific problem to be solved, why the solution is important, and how the solution will be used. Some of the more significant need statements that have been input to the program are listed by code and title in Table 1. The major effort of the program is directed toward control at the source rather than treatment and reclamation of degraded water. The program leaders collaborate in assigning priorities to the research needs in accordance with resources available to perform the required studies.

TABLE 1

RESEARCH NEED STATEMENTS
PPBS 13030 SUBPROGRAM ELEMENT, IRRIGATION RETURN FLOWS

Need Code	Title
XAZ	Agricultural Wastewater Characteristics
UCA	Mineral Quality Relationships of Percolating Irrigation Waters
RBL	Salinity Control Through Farm Irrigation Water Management
UBH	Treatment of Waste Water from Irrigated Agricultural Areas
PCS	Leaching, Reclamation, and Drainage Requirements in Irrigated Areas
RBM	Prediction of Salinity in Irrigation Return Flows
PCR	Alternate Procedures for Collection, Storage, and Reuse of Irrigation Return Flows
RBK	Economic Evaluation as a Function of Salinity in Irrigation Return Flows
CBL	Reduction of Salt Toxicity to Irrigation Crops by Chelation
CBK	Genetic Development of Salt Tolerant Irrigated Crops
WOC	Reclamation of Irrigation Return Flow for Reuse (Related to PCR)
WOD	Evaluation of Subsurface Irrigation Method as Means of Salinity Control in Irrigation Return Flow
WOE	Boron Removal from Irrigation Supply and Waste Water
WOF	Automated Irrigation Systems for Better Water Management and Salinity Control in Return Flows
WOG	Control of Nutrient Losses in Irrigation Return Flows
PAF	Effects of Irrigation Management, Climate, Soil, Plants on Irrigation Water Quality (Related to RBL)
UBI	Source Control of Wastes from Irrigated Agricultural Areas (Related to RBL)
PAG	Salt Load in Solution Pick-up and Evapotranspiration Processes (Related to UCA)
PAI	Chemical Reactions and Equilibrium Relationships Between Quality and Quantity of Irrigation Return Flow (Related to UCA)

SECTION III

RESEARCH AND DEVELOPMENT PROGRAM

The first project was an in-house effort conducted in cooperation with Agronomy Department personnel from Oklahoma State University at the Irrigation Research Station, Altus, in southwestern Oklahoma. The study spanned one growing season and was conducted on a 7-acre cotton field. This pilot field study yielded data on the quantity and quality of irrigation water applied versus surface return flow and quality of soil water percolating below the plant root zone. The results of that study were published as Oklahoma Agricultural Experiment Station Bulletin B-684 titled "Degradation of Water Quality in Irrigation Return Flows" (3).

One of the earliest and most urgent needs of the program was that of a comprehensive literature review and preparation of a state-of-the-art report. A contract was negotiated with Utah State University Foundation to produce the report, which was completed in May 1969 and published under the title "Characteristics and Pollution Problems of Irrigation Return Flow" (2). It provided a broad review of irrigation practices, mechanics of return flow, and the many complexities of water quality problems associated with the soil-plant-water system. As one of the major objectives of the report, research needs and recommendations were stated. The report was significant in that it pointed out the lack of information related directly to the control of water quality degradation by irrigation return flows.

Current Research

The major emphasis toward the objectives of the program to date has been through the administration of grant funds to support extramural research projects. Limited manpower has served to curtail in-house research, but it is expected that this effort will be expanded in the next few years. One major in-house effort has been the cooperative interagency research conducted at the Interagency Agricultural Waste Water Treatment Center at Firebaugh, California. The cooperating agencies were the California Department of Water Resources, U.S. Bureau of Reclamation, and the Robert S. Kerr Water Research Center, EPA. The combined activities of the research group represent the current activity under research need UBH, "Treatment of Waste Water from Irrigated Agricultural Areas." The project was initiated late in FY-1967. It was originally planned for a three-year duration and subsequently extended through FY-1971 for completion of economic and operational studies. St. Amant and Beck (4) have described the organization and objectives of the interagency research group. The main objective of the research was to develop economically feasible methods of removing nitrogen, mainly in the nitrate form, from the agricultural wastewaters of the San Joaquin Valley. Both assimilatory

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(algae stripping) and dissimilatory (bacterial denitrification) biological methods have been developed and shown to be feasible. Final reports of the studies are being completed and will be printed in the near future.

Another interagency research effort has been activated under research need RBM, "Prediction of Salinity in Irrigation Return Flows," in cooperation with the Bureau of Reclamation. The objective of this research is to develop a basin model that will be able to predict the salinity changes resulting from irrigation in a basin area. The computer model is being developed and tested through a detailed evaluation of water and salt movement in the Ashley Valley at Vernal, Utah. The model will be evaluated further by later studies in other basin areas. The model will be useful in predicting the effects of irrigation on water quality in areas prior to irrigation development. The study does not include changes in water management and fertilizer practices.

Whereas the two projects previously described deal with treatment and prediction, respectively, other active and pending research is primarily concerned with water management practices. Utah State University is being supported with a grant titled "Quality of Irrigation Return Flow." The project is investigating several related problems that affect the quality of irrigation return flow. Four sub-project areas being studied are:

a. Precipitation mechanisms in soils as they affect water quality;

b. Prediction techniques for simultaneous movement of salt and water in soils and their response to changes in quality of irrigation water and irrigation management;

c. Managing water in the soil-plant system to control the quality and quantity of return flow; and

d. Contamination of surface and drainage water with soil and foliar herbicides.

This project partially meets need statement UCA, "Mineral Quality Relationships of Percolating Irrigation Waters." Portions of sub-projects (b) and (c) are being conducted by field studies in the Ashley Valley at Vernal in order to cooperate with the USBR prediction study. Information interchange between the two projects has been helpful to both. That portion of the project is also closely related to need statement RBL, "Salinity Control Through Farm Irrigation Water Management." The final report from this project will contain recommendations for solving specific water quality problems associated with irrigation return flow.

A three-year research project has been initiated with a grant to Texas A&M University Research and Extension Center at Lubbock dealing with

the effects of subsurface irrigation and fertilizer application methods on the nitrates and salts in percolating irrigation water. Groundwater contamination already exists in the area of this study, and it is designed to produce positive solutions for that problem. The results of this study will contribute significant knowledge regarding irrigation methods and fertilizer practices and their effects on the quality of return flows. This project is designed to partially meet needs WOD, "Evaluation of Subsurface Irrigation Method," and WOG, "Control of Nutrient Losses." In addition, it is closely related to need RBL, "Farm Irrigation Water Management."

Another three-year grant has recently been awarded to New Mexico State University to study the quality and quantity of return flow as influenced by trickle and surface irrigation methods. Automation of the irrigation systems permits this research to contribute to needs RBL, "Farm Irrigation Water Management," and WOF, "Automated Irrigation Systems for Better Water Management and Salinity Control." The study is being conducted in the Rio Grande Valley near Las Cruces and should contribute significantly toward the potential control of salinity contributed to the Rio Grande in that area.

A demonstration project has been completed in the Grand Valley of western Colorado which involved the installation of canal lining in portions of the valley. Preconstruction data on the quality of water draining from the area were gathered. Evans (4) has described the salinity problems of Grand Valley and the approach to solutions through canal lining. Post-construction evaluation of the effects of canal lining on the quality of the drainage and the salt load contributed to the river from the area is being made by Colorado State University personnel. Studies in the Upper Colorado River Basin have shown that an estimated 18 percent of the salt load at Hoover Dam originated from the Grand Valley area. The findings of this study will partially meet need UBI, "Source Control of Wastes from Irrigated Areas," and may be applicable to other areas which produce high salt loading to the receiving stream.

Washington State University was recently awarded grant funds for the "Evaluation and Demonstration of Irrigation Methods and Practices to Reduce Contamination in Irrigation Waste Waters." The proposed research is an extension of an ongoing project to include water quality measurements. This project will make a significant contribution to research need RBL, "Salinity Control Through Farm Irrigation Water Management."

Another program effort supported by grant funds to Colorado State University is titled "Irrigation Return Flow Quality Literature Abstracting." Literature is being searched and abstracted, starting with the year 1968 and continuing through 1972. The abstracts will be accumulated and published periodically in report form. Abstracts are also furnished to the Water Resources Scientific Information Center (WRSIC) for inclusion

in their publication, "Selected Water Resources Abstracts." An additional task being completed under the terms of this active grant is the preparation of a report covering "Research Needs in Irrigation Return Flow Quality Control." The major topics covered include:

a. Define the major geographic areas where irrigation return flow problems exist.

b. Specify the major water quality problems arising from irrigation return flows and how these differ by regions.

c. Propose potential solutions required to alleviate and/or control water quality degradation by irrigation.

d. Define specific research activities most urgently required to design and implement the potential solution to solve the critical problems.

This report will be useful in future program planning. It will provide specific problem definitions that are needed to develop an integrated program for achieving solutions needed to establish guidelines for the control of pollutants arising from irrigated areas. It will be published and made available to interested research groups in water quality control investigations.

SECTION IV

FUTURE PROGRAM DEVELOPMENT

Water quality degradation is a serious matter to agriculture, as well as other water users. It has been pointed out (5) that we approach the need for water quality management with little preparation in either policy or technology for upgrading the quality of irrigation return flow. The unfortunate prospect is that irrigation will continue to contribute to the decline in water quality in many areas unless better systems for managing the quality of return flows are found. Agricultural scientists face a challenging future in achieving these objectives.

It is recommended that field research sites be used for specific studies required to improve water quality in the major problem areas. A number of considerations are of paramount importance for recommending and initiating studies at outlying field stations.

First of all, the new technology needed must be evaluated and demonstrated in field plots. The wide variety of water quality problems can not be investigated at one location under one set of conditions, including soil profile characteristics, irrigation water quality, climate, cropping system, etc. The significant water quality problems resulting from irrigation differ in widely separated irrigated areas with differences in soils, climate, crops, and management practices. Therefore, several field site locations should be selected on the basis of suitability for providing the technology needed to improve water quality in the major problem areas.

A second major consideration concerns the capital investment that would be required for the purchase, preparation, and equipping of field stations to study irrigation return flow problems. As a beginning for this proposed program, it is recommended that cooperative agreements with existing agricultural experiment stations be considered. These agreements should vest control of the study sites and operations in the program leaders. The use of existing irrigation facilities, buildings, laboratory space, etc., would be arranged by contract. The contractual arrangements could also provide additional manpower for field work, sample collection, etc., as required.

Thirdly, this approach would provide a means of cooperative in-house and extramural effort that would be most effective in developing solutions to protect the environment. It would require that program personnel be stationed at each field site to serve as project director. The director would have responsibilities for assisting in planning and conducting the specific studies. His duties would also include analysis of data and reporting the findings. Depending on the scope of the research at the field sites, it is conceivable that additional program personnel would be required as support to the project director.

Finally, the priority of research sites, their location, and the problems to be studied would be based on the relative magnitude of the water quality problems from irrigation return flows and the potential for improving water quality.

Extramural research, development, and demonstration grants to answer high priority needs will continue to be a major part of the future program. Recommendations for research proposals are based upon scientific merit and program interest. First of all, the proposed research design must be based on scientific principles. It must be carefully conceived and planned to assure that the stated objectives will be achieved. Uniqueness and originality are important points for consideration. Use of accepted analytical methodology and technical procedure is required. Assurance of adequate analytical quality control, data evaluation, and interpretation procedures is necessary. The program interest evaluation is concerned with fitting the research to the program needs having high priority and which are not presently being funded elsewhere. The research must be geared to solving a specific problem, and a need for the study must be shown. When these criteria are met, a research proposal is well on its way to favorable consideration.

Future program plans clearly indicate a coordinated effort involving both in-house and extramural research activities. The extent to which the program objectives can be met will depend in large measure upon the resources, both professional manpower and funds, made available to the program. In order to accomplish the program goals as set forth, an increased level of resources will be required. Program goals and milestones have been set forth in a report on "National Plan and Strategy for Water Quality" (6) in the following sequence:

1. Develop an inventory of and evaluate water quality problems from irrigation return flows (by 1972).

2. Conduct technical studies to characterize magnitude of salinity, nutrient and sediment problems (1972-1974).

3. Demonstrate measures and practices to prevent or control salinity pollution (1973-1975).

4. Demonstrate methods to treat, control, or prevent nutrient pollution (1973-1975).

5. Develop and demonstrate sediment prevention and control measures (1973-1975).

6. Develop and demonstrate measures to prevent or control pesticides pollution (1973-1975).

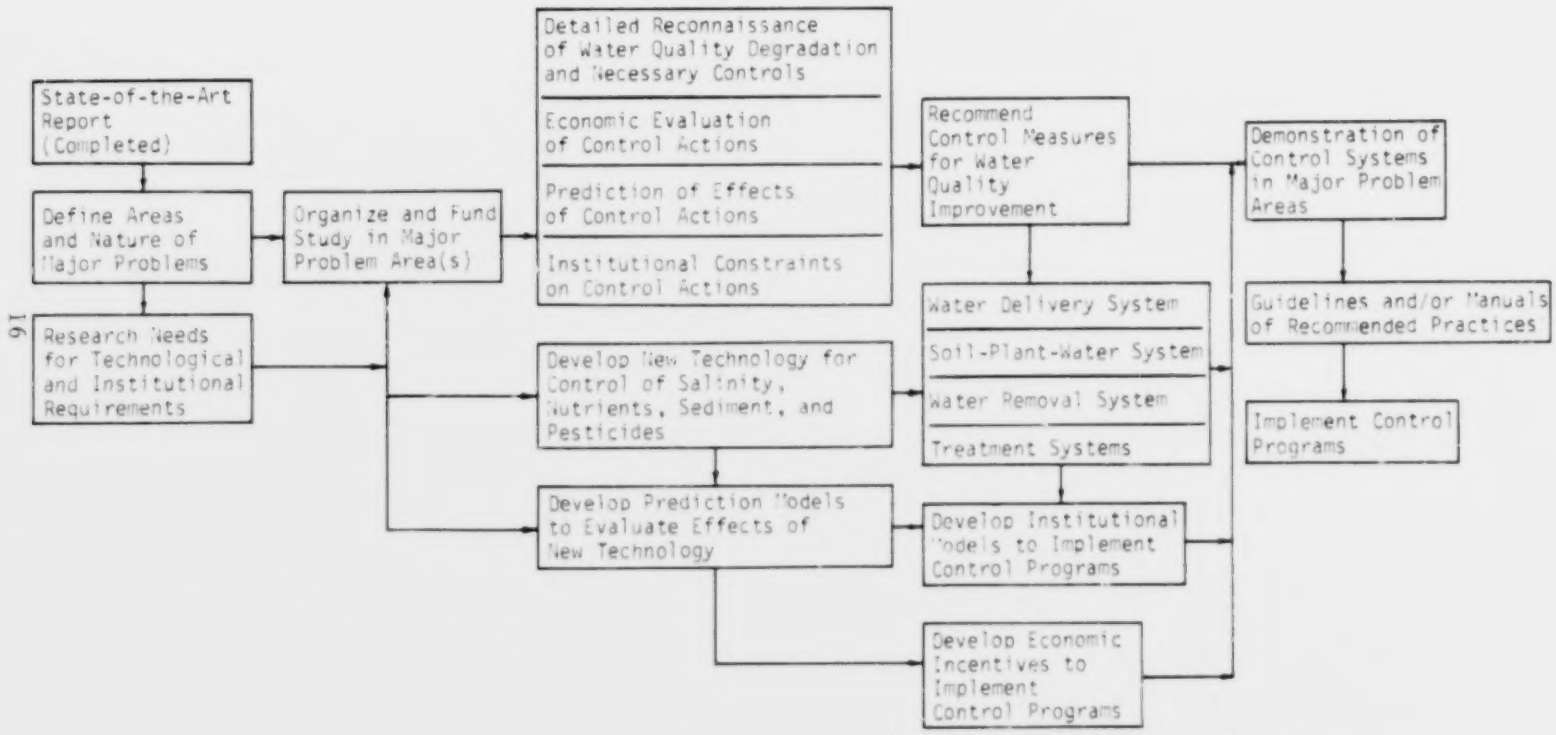
7. Guidelines and/or manuals of recommended practices for control of irrigation return flow problems (1976).

A more detailed analysis of future program plans is provided schematically in Figure 2. Program goals and milestones are indicated in logical sequence. This sequence could be repeated in each major study area involved. The suggested time-sequence of accomplishments are considered to be realistic even though they do not coincide exactly with those listed above. The overlapping of time periods indicates latitude in initiating the various activities and advancing more rapidly toward the program goals.

Figure 2

NATIONAL IRRIGATION RETURN FLOW RESEARCH, DEVELOPMENT AND DEMONSTRATION PROGRAM

Goals and Milestones


State-of-the-Art Report (Completed)
Define Areas and Nature of Major Problems
Research Needs for Technological and Institutional Requirements
Organize and Fund Study in Major Problem Area(s)
Detailed Reconnaissance of Water Quality Degradation and Necessary Controls
Economic Evaluation of Control Actions
Prediction of Effects of Control Actions
Institutional Constraints on Control Actions
Develop New Technology for Control of Salinity, Nutrients, Sediment, and Pesticides
Develop Prediction Models to Evaluate Effects of New Technology
Recommend Control Measures for Water Quality Improvement
Water Delivery System
Soil-Plant-Water System
Water Removal System
Treatment Systems
Develop Institutional Models to Implement Control Programs
Develop Economic Incentives to Implement Control Programs
Demonstration of Control Systems in Major Problem Areas
Guidelines and/or Manuals of Recommended Practices
Implement Control Programs
FY 1972
FY 1973-74
FY 1973-75 (3 years)
FY 1975-77 (3 years)
FY 1977-78 (2 years)

SECTION V

POTENTIAL CONTROL MEASURES

It seems appropriate at this point to present a brief discussion of the more apparent possibilities for achieving some measure of control over the quality of irrigation return flows. Some control technology has already been developed and the major missing link is the evaluation of the effects on the quality of return flows and subsequent impacts on the quality of receiving streams. In addition, the program must concern itself with the institutional factors affecting the acceptance and implementation of effective control measures. This aspect presents some of the more difficult problems. It, therefore, seems assured that the future program will be heavily involved in evaluation of effects of control measures, technology transfer activities, and studies of institutional factors.

Potential control measures may involve physical changes in the system, improvements in present management and cultural practices, or changes in the institutional influences upon the system. Since irrigation return flow is an integral part of the hydrologic system, control measures for managing the return flow from an irrigated area must be compatible with the objectives for total water resource management and development.

The irrigation return flow system (Figure 1) can be subdivided into three major sub-systems: (a) water deliver; (b) the farm; and (c) water removal. Water delivery includes the transport of water and pollutants from the headwaters of the watershed to the point of diversion, thence to the individual farm. The farm sub-system begins at the point where water is delivered to the farm and continues to the point where surface water is removed from the farm. Also, the farm sub-system is defined vertically as beginning at the soil surface and terminating at the bottom of the root zone. Water removal includes surface runoff from the farm and water moving below the root zone. Quality problems in the water removal sub-systems are minimized by having highly efficient water delivery and farm sub-systems. Minimizing the quantity of surface runoff will assist in alleviating water quality problems due to sediments, phosphates, and pesticides; whereas minimizing deep percolation losses from irrigated lands will reduce quality problems due to salts, including nitrates, in areas where salt pickup occurs.

Water Delivery System

The importation of high quality water from adjacent river basins, weather modification to increase precipitation and runoff from the watersheds, bypassing mineralized springs, evaporation reduction from water surfaces, and phreatophyte eradication are some of the available

measures for improving the quality of water diverted from a river. Consequently, they play a role in the management of the irrigation return flow system. The amount of water passing key points in the irrigation delivery system must be known in order to provide water control and attain a high degree of water-use efficiency.

Canal and Lateral Lining - Many unlined irrigation canals traverse long distances between the diversion point and the farm land. Seepage losses may be considerable, resulting in low water-conveyance efficiencies. Canal lining has traditionally been employed to prevent seepage and the costs of lining have been justified primarily on the basis of the value of water saved. The possibility that water seeping from canals may greatly increase the total contribution of dissolved solids to receiving waters has only recently been given serious attention. It has been reported (2) that average seasonal canal losses varied from 13 percent of the diversion on the Uncompahgre Project, Colorado, to 48 percent of the diversions on the Carlsbad Project, New Mexico. If soils along the canals are high in residual salts, the salt contribution from this source could easily exceed that leached from the irrigated land to maintain a salt balance. The salt from this source could be largely eliminated by canal lining. Evaporation losses from canals commonly amount to a few percent of the diverted water. A closed conduit conveyance system has the advantage of minimizing both seepage and evaporation losses. Either lined canals or closed conduits will reduce evapotranspiration losses due to phreatophytes. The closed conduit system requires less land and provides better water control than a canal system. Water quality improvement may very well prove to be the greatest economic justification for canal lining and/or closed conduit systems.

Farm Water Management

Due to the nature of irrigated agriculture, whereby salts must be leached from the root zone, optimum control will require improvements in on-the-farm water management. In order to attain high irrigation application efficiencies, the timing and amount of water being delivered to the farm must be controlled. At the same time, the farmer must be capable of controlling the water supply as it moves across the farm. Control of the water requires regulating the water delivery rate, as well as measuring the water applied.

Application Methods - The effect of methods of application on the quality and quantity of return flow has not received detailed study. Conventional surface and sprinkler methods are most commonly used because of their low initial cost and ease of adaptablility to a wide range of field and surface conditions. New and unique approaches to application methods

need to be found. Two that appear to offer great promise in the control of both quantity and quality of return flows are subsurface application (7) and drip or "trickle" methods (8).

With subsurface irrigation, water can be applied to the crop in small amounts and at frequent intervals so that evaporation and the resultant increase in salt concentration are reduced. The water content of the soil is maintained below field capacity so that some precipitation can be stored in the soil, introducing an additional dilution factor. Comparable crop yields have been produced with 40 to 50 percent less water than is required with furrow irrigation. Thus, limited water supplies can be extended or the acreage which can be irrigated with a given water supply can be increased. Application rates can be closely controlled and the method can be readily automated.

The drip irrigation technique has aroused enthusiastic interest in Israel (8). The major advantages include increased crop yield, reduced salinity damage, and shortened growing season with earlier harvest. The method involves the slow release of water on the surface near the base of the plants. Evaporation losses are greatly reduced and moisture release is confined to the area of the plant root system.

Both of these methods need to be evaluated as to their potentials for reducing salinity in return flows, increasing yields with limited water supplies, and reducing fertilizer nutrient losses by leaching. Liquid fertilizers can be applied by either of these methods in small controlled doses throughout the growing season. The potential economic advantages of saving both water and fertilizer nutrients and reducing labor costs of operation make these methods attractive. Economic evaluation might show that these benefits would largely offset the initial cost of installation.

Irrigation Scheduling - Historically, irrigation has been practiced more as an art than a science. When left to his own discretion, a farmer may delay irrigation until the crop is stressed and then apply more water than actually needed, resulting in poor water management and reduced yields. This two-fold problem is presently being overcome by irrigation scheduling based on climatic, soil, and crop data (9, 10). Commercial firms gather the data and notify the irrigator when to irrigate a certain crop and the amount to be applied. The farmer pays a fee for the service and is thus relieved of the responsibility of deciding when is the best time to irrigate.

Experience in southern Idaho and the Salt River Project in Arizona during the past few years clearly indicates increased yields due only to scientific scheduling of irrigation. To date there has been little reduction in water use, although it seems likely that this would occur with time as the farmer gains more knowledge of actual crop requirements. This

approach offers great promise as a water management control tool and may provide the knowledge and experience needed to overcome present antiquated institutional, political, and legal influences that present the major stumbling blocks to water management reform.

Control of Leaching - Another possible control measure is closely controlled leaching to minimize salt pickup from underlying geologic formations. The most drastic action would be to eliminate irrigation in areas of high salinity such as those where the soils are formed from and overlying salty shales. Preventing or reducing the amount of water penetrating to deeper saline strata would also reduce the salt load in return flows. The use of natural or artificial barriers below the root zone, coupled with drainage systems to intercept drainage water before it reaches the deeper strata, would be effective. Regulating the amount of water applied to the land and thereby regulating the amount of drainage constitutes a combination of controlled leaching and dilution. Further study is needed to evaluate this approach to the control of salinity in return flows.

Fertilizer Nutrients - Nitrogen-use efficiency may be improved by the use of slow-release fertilizers or by adding liquid fertilizers frequently through the irrigation water supply. The present higher cost of these products is the chief deterrent to increased acceptance. If regulations were imposed to require their use in areas where nitrogen problems occur, increased sales volume would act to lower the cost of production and a more favorable pricing schedule would result. An added advantage of slow-release fertilizers is fewer applications per season. Further evaluation of these products with regard to improved quality of irrigation return flow is required.

Tailwater Recovery - In water-short areas, tailwater recovery is practiced. In addition to increasing water-use efficiencies, the practice serves as a control of sediment erosion with its adsorbed pesticides, phosphorus, heavy metals, etc. The water recovered is returned to the irrigation supply rather than released to surface drainage systems. The quality of surface return flows is only slightly degraded and entirely satisfactory for reuse after settling of suspended solids (3, 11). Improved irrigation practices would likely result in order to minimize the quantity of water and sediment from cropland. In extreme cases, enforceable regulations may be required to effectively control tailwater losses and protect downstream water users.

Cultural Practices - In areas of tight soils and saline water supply, cultural practices become significant if crops are to be grown sucess-

fully. Under these conditions, management alternatives are: (a) more salt tolerant crops; (b) special deep tillage may be required; (c) leach in the off-season or alternate years; (d) careful seed-bed preparation and seed placement; and (e) close control of timing and amount of water applied. Special practices such as mulching and reduced tillage may be effective in reducing soil water evaporation. These special cultural practices are more often aimed at crop production under less-than-ideal conditions than toward improved quality of return flow, although the two often go hand-in-hand.

Water Removal System

The water removal sub-system transports surface runoff and subsurface drainage from irrigated lands. The tailwater may be returned to the delivery system, become water supply for an adjacent farm, or be transported back to the river. Subsurface drainage may seep into open drains or to lower lands along the river where salt damage often occurs. There are essentially three management alternatives for preventing or minimizing the quantity of pollutants discharged to the river: (a) divert the drainage to some discharge point or sink area away from the river; (b) treatment for removal of pollutants prior to reuse or discharge; and (c) provide dilution to minimize the detrimental effects. Economic considerations are of prime importance in each of these alternatives.

Diversion - Subsurface return flows are often collected by tile drainage systems underlying irrigated areas. Being thus collected into a common sump or open drain, they may easily be diverted to some point away from the river. The proposed drainage system for the San Joaquin Valley and the present system for the Wellton-Mohawk district in southern Arizona are examples of return flows being carried away without returning to the river or supply canal system. Return flows diverted to suitable sink areas may provide wildlife habitat. Either of these alternatives prevents the addition of pollutant loads to the river system. Other considerations, such as water rights of downstream users, may be important in selecting suitable diversion schemes for irrigation return flows.

Treatment - The present high cost of desalination processes is the chief deterrent to their use for reclaiming saline water. Only in extreme cases would they prove economically feasible. Recent cooperative research at Firebaugh, California, conducted by the Environmental Protection Agency, Bureau of Reclamation, and California Department of Water Resources has developed methods of removing nitrates from irrigation return flows. In these studies, both algae stripping and bacterial denitrification proved feasible to treat agricultural tile drainage prior to its release into San Francisco Bay via the San Joaquin drainage canal

system. Final plans for the treatment facility are being considered.

Dilution - Dilution of return flow occurs naturally in nearly all upstream irrigated areas, where drainage waters and other return flows are diluted in the main stream so that the resultant quality is acceptable downstream for irrigation and other beneficial uses. Multipurpose reservoirs have provided storage capacity for low-flow augmentation as well as other beneficial purposes. Stream-flow regulation can be beneficial for quality control, although such benefits are usually incidental to other primary requirements for regulated flow.

There are limitations to the effectiveness of dilution as a means of managing return flows. The major physical limitation is the amount of high quality water that can be stored and released at the desired times to achieve maximum benefits from dilution. The legal implications of obtaining water rights for the purpose of dilution could be exceedingly complex. In general, such practices would result in diminished supplies for other purposes and this in areas where water rights already exceed the supply. Presently, it appears that stream-flow regulation for quality control of irrigation return flows cannot be relied upon as a useful management technique.

SECTION VI

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27 Abstract
The status of the National Irrigation Return Flow Research and Development Program is presented. Current research projects and future program development are discussed. The report represents the position of the Environmental Protection Agency (EPA) with regard to the develcpment of effective controls on the quality of irrigation return flows. Program goals and milestones are outlined. A number of potential control measures are discussed. Improvements in the water delivery system, on-the-farm water management, and the water removal system are considered with respect to improving the quality of irrigation return flows and decreasing the degradation of receiving waters. Research and investigations are needed to evaluate the effectiveness of potential control measures. Demonstrations and educational activities will be required to overcome institutional, political, and legal constraints to water management reform. (Law-EPA)

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